Noise: A Limiting Factor for the Use of Modern Weapon Systems?

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NOISE OF MODERN WEAPON SYSTEMS

Continuous and/or impulse noises produced by modern weapon systems constitute a threat for the health of the soldier and impede his operational ability. Moreover, their levels often exceed the statutory exposure limits as well for the users (unprotected and protected ears) as for the nearby community.

1.0 INTRODUCTION

Modern weapon systems produce very high levels of impulse and/or continuous noise. Exposure to intense noise induces mechanical and/or metabolic damage to the inner ear.
At the hearing threshold the amplitude of the displacements of the sensory structures of the inner ear (stereocilia) is about 10^{-12} m (1/100 the diameter of the hydrogen atom). At 120 dB this amplitude reaches 1 micrometer (corresponding to an angular deflexion of ~ 15 degrees of the stereocilia). Depending on the level of the noise, these structures may break off immediately (i.e., for large continuous and/or impulse noises) or be overpowered by fatigue failure mechanisms (figures 1 and 2).

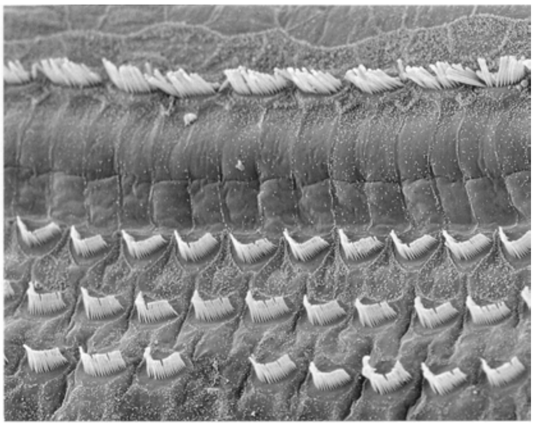

Figure 1: Intact hair cells and stereocilia

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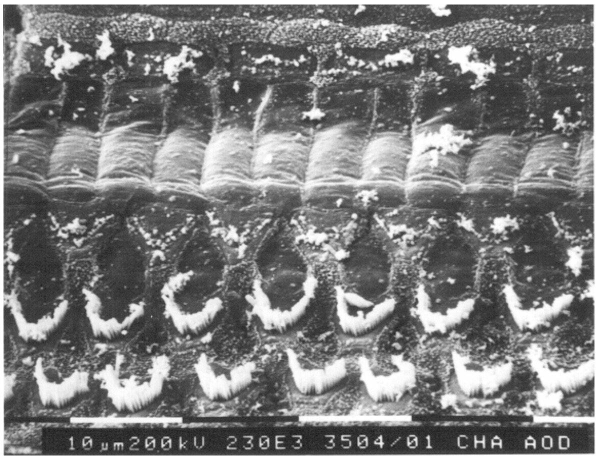

Figure 2: Damaged hair cells and stereocilia

Moreover, immediately after an exposure to a loud noise, one can observe a swelling of the afferent synapses (the interface between the sensory cells and the fibers of the auditory nerve that conveys the hearing message to the upper auditory centers) due to the glutamate excitotoxicity (figure 3). In the worst cases, the synapses burst and the nerve fibers disconnect from the sensory cells (figure 4).

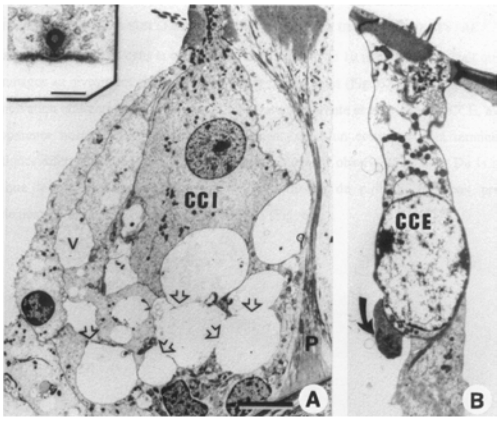

Figure 3: Swelling of the afferent synapses under the Inner Hair Cells (CCI) (CCE: Outer Hair Cells)

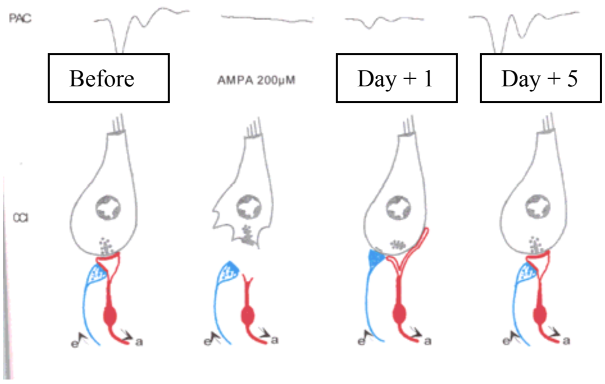

Figure 4: Schematic representation of synaptic damage due to metabolic excitotoxicity

Over-exposure to noise damages permanently the sensory cells and induce elevated threshold (Permanent Threshold Shift: PTS), impairment of frequency selectivity, recruitment and tinnitus [1].

2.0 HEARING DAMAGE CONSEQUENCES

2.1 Operational consequences

The hearing losses and the decrease in frequency selectivity induce difficulties to detect, localize and identify acoustic sources in the environment and impedes the efficiency and the security of the soldier. Moreover, the impairment of speech intelligibility (especially in noisy environments) can drastically reduce the global performance of complex and expensive weapon systems [2] (figure 5).

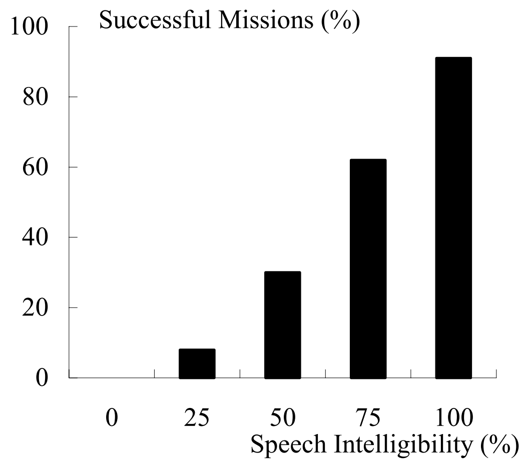

Figure 5: Tank performance: percentage of successful missions (including navigation, reporting and gunnery) as a function of speech intelligibility [2]

2.2 Financial consequences

The acoustic trauma represents the first cause of morbidity in the military during peace time !
The Noise-Induced-Hearing-Losses are responsible for many expenses.
Soldiers suffering large PTS can be definitively withdrawn from front line service. For specialized personnel high educational and training expenses may be definitively wasted. Moreover, PTS is considered as war injury and must by compensated [3].
For this cause, in 2003, 548 million dollar have been distributed to 74,363 US veterans (figure 6).

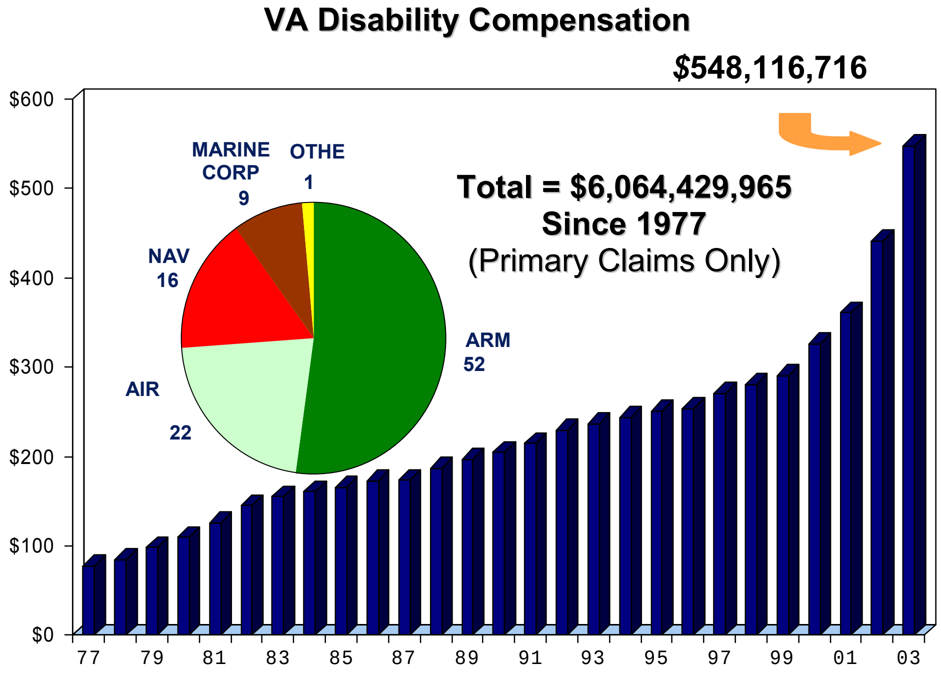

Figure 6: Hearing Loss disability costs in the USA [3,4]

In the UK, in 2002, 20% (£40m) of the litigation claims are directly related to noise and vibration and this figure is doubling every 4 years. There are also additional costs: retraining of downgraded personnel, training of new replacement recruits (~ £2m per head aircrew) [5].
In France, the annual cost of the compensations is evaluated to 50 million euros.
In Belgium, about two thirds of the 6 million euros paid yearly to the veterans for all kinds of disabilities correspond to NIHL.
Moreover, the medical treatments (of which the efficiency is questionable) are also very expensive [6].

3.0 CONTINUOUS NOISE

Heavier, faster, and more powerful weapon systems produce higher continuous noise levels. In the following, some examples will be presented for a better understanding of the problem.

3.1 Jet noise

The new fighters are probably the noisiest military weapon systems. The spectrum of the noise is generally broadband with a maximum at mid-frequencies (~ 1 kHz).

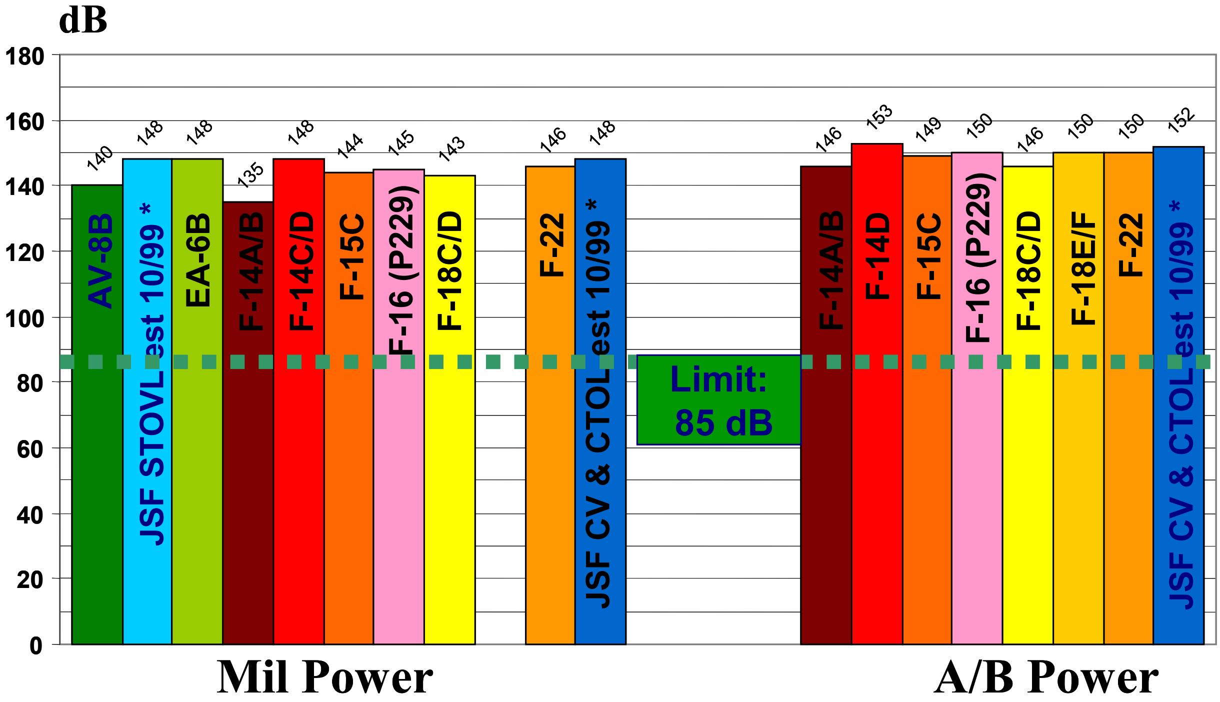

Figure 7: Worst Case Aircraft Noise Levels at 15 meters in dBA [4]

Individuals located in the immediate vicinity of these planes (ground crew, AC deck crew…) may be exposed to levels > 150 dB(A). In these conditions, the present hearing protection devices cannot afford enough attenuation [4]. Communication between the members of the crew is impossible. Because of the noise in the immediate vicinity of the plane *and* the noise inside the cockpit (≥120 dB in the new fighters) (see also figure 8), communication between the ground crew and the pilot may be very difficult if not impossible especially during specific takeoff and landing operations (JSF) [5].

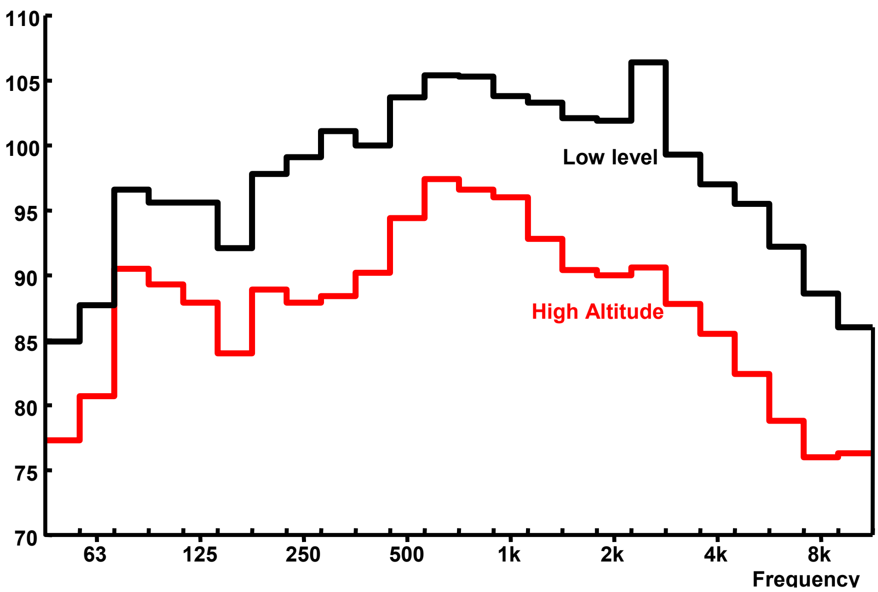

Figure 8: HARRIER cockpit noise (low level and high altitude flight) in dB SPL [5]

Jet noise has also a large impact on the environment. The annoyance corresponding to the extended noise footprint of the new fighters could limit their normal training operations in densely populated areas (community noise) (figure 9).

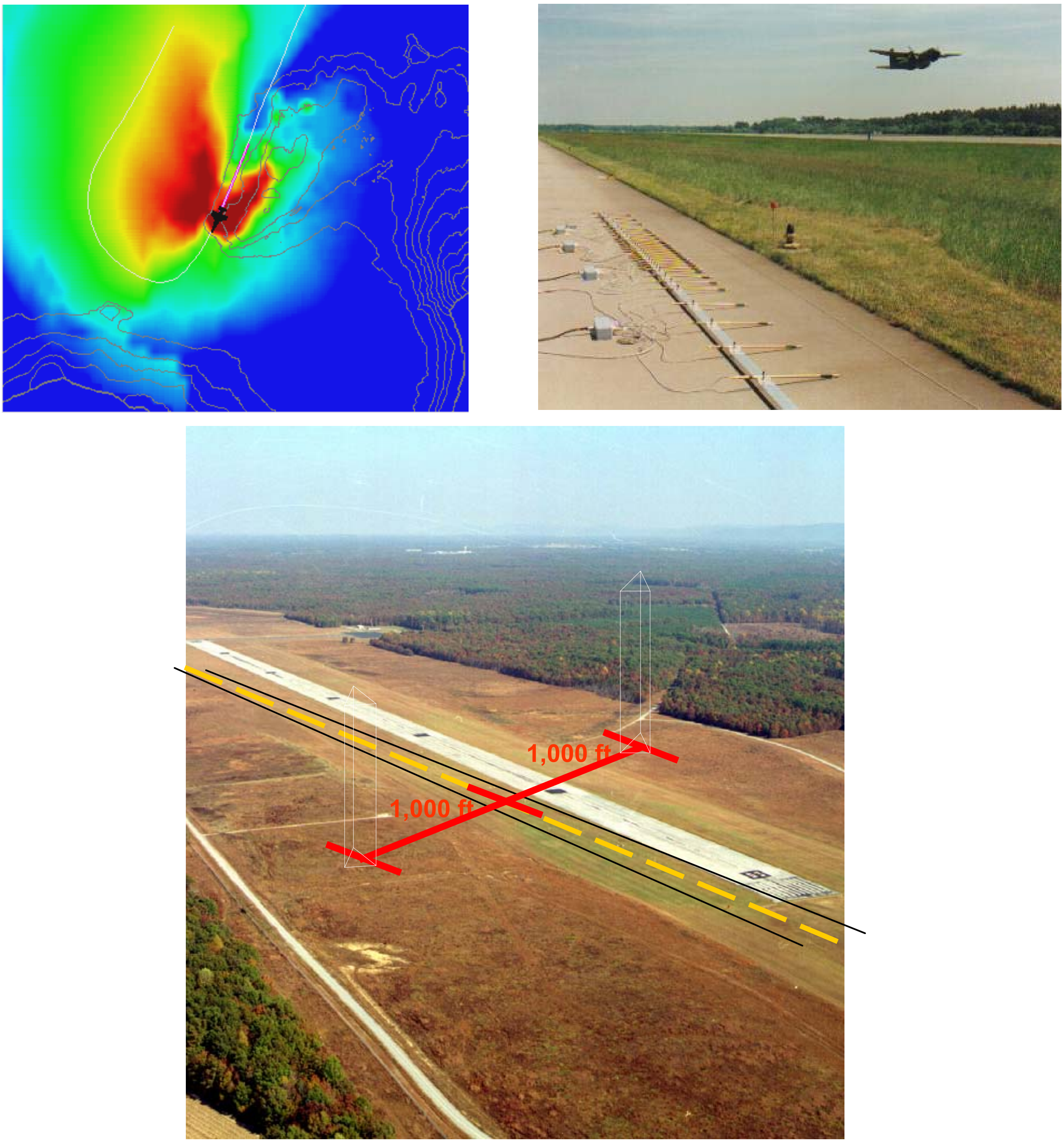

Figure 9: Noise footprint, present and future measurement installations of the US Air Force and FAA (dB Towers) [courtesy R. McKinley, AFRL/HECB Dayton]

3.2 Helicopter noise

The noise in the cabin of helicopters is made of low (rotor), medium (gearboxes) and high (jet engine) narrow band discrete tones, superimposed on a low level broadband background noise [5].

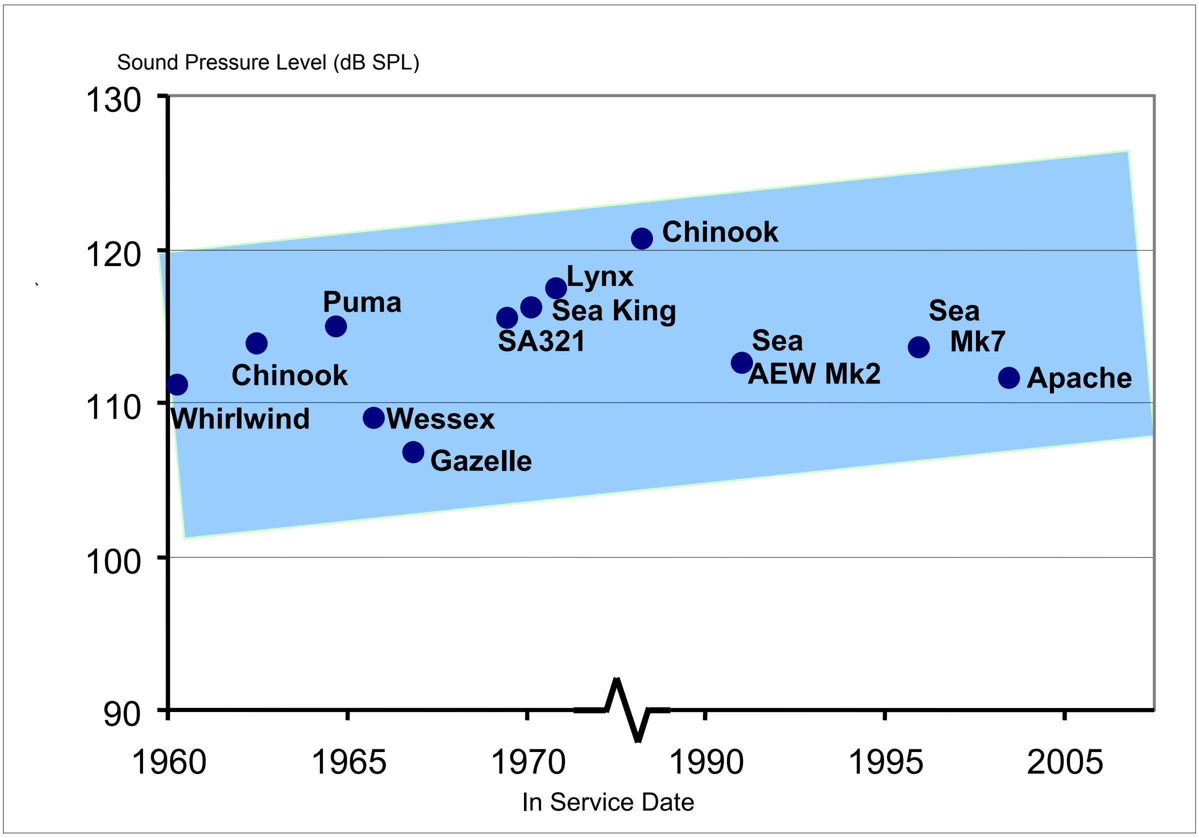

Figure 10: Noise levels in helicopters [5]

As the noise in a helicopter is rich in low frequency sound, the limited low-frequency attenuation characteristics of a helmet or headset will let through almost all of the low frequency noise [4,8]. These low frequencies will mask (nonlinear masking) the speech frequencies and impair the communication [7,8,9]. However, at the higher frequencies where the helicopter generates little noise and the helmet attenuation is at its maximum, the noise levels at the aircrews' ear will be low [5].

3.3 Land-vehicles noise

The A-weighted noise level at the positions of the crew members is reported for different land-vehicles in figure 11 (the dark colored bars span two standard deviations around the mean A-weighted sound level) [5,10]. Heavy tanks show the highest interior noise level (~120 dBA) and the spread within this category is small. The figure 12 indicates that the noise is maximum at low and very low frequencies (around 100 Hz) [5]. In these conditions and given the attenuation afforded by the passive hearing protectors there is a significant hazard for hearing and the communication is badly impaired: nonlinear masking of the speech frequencies by the very low ones [7,8,9]. Because of this masking, the crew members adjust the volume control of intercom and radio systems to very high settings (sometimes corresponding to speech-to-noise ratios in excess of 10 dB). When voice communication is frequent, a significant increase is made to the overall noise dose [10,11].

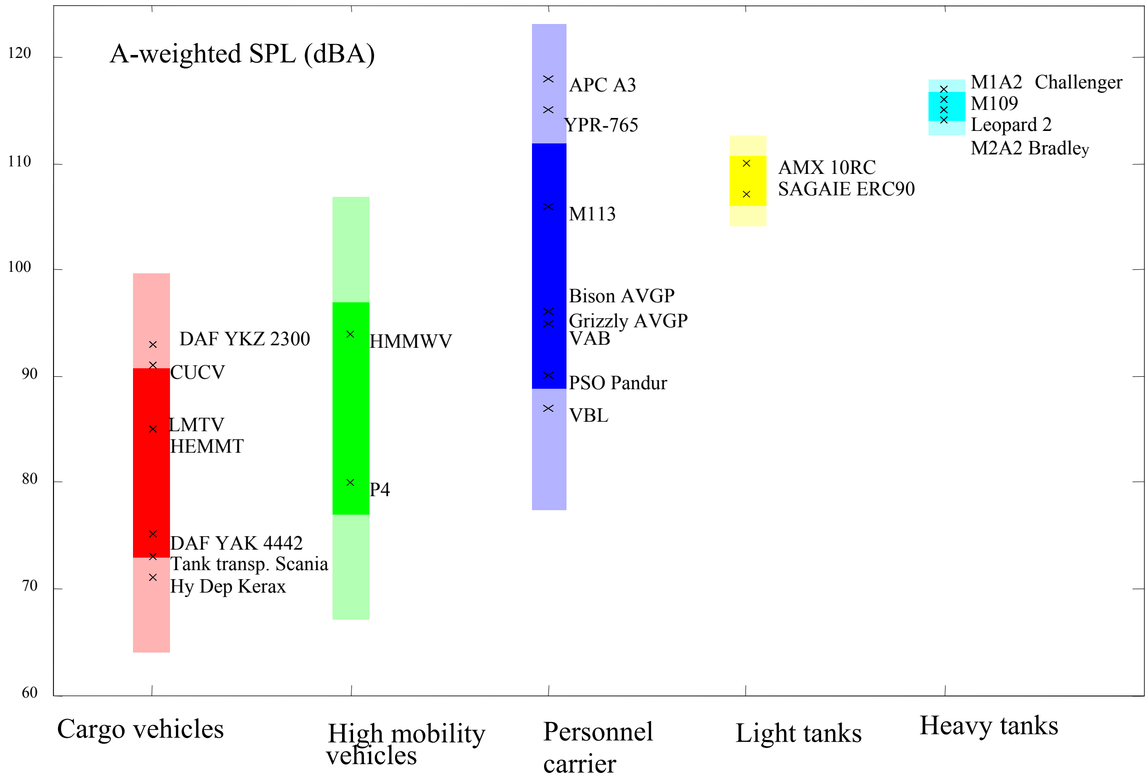

Figure 11: A-weighted interior noise level in land-vehicles [5,10]

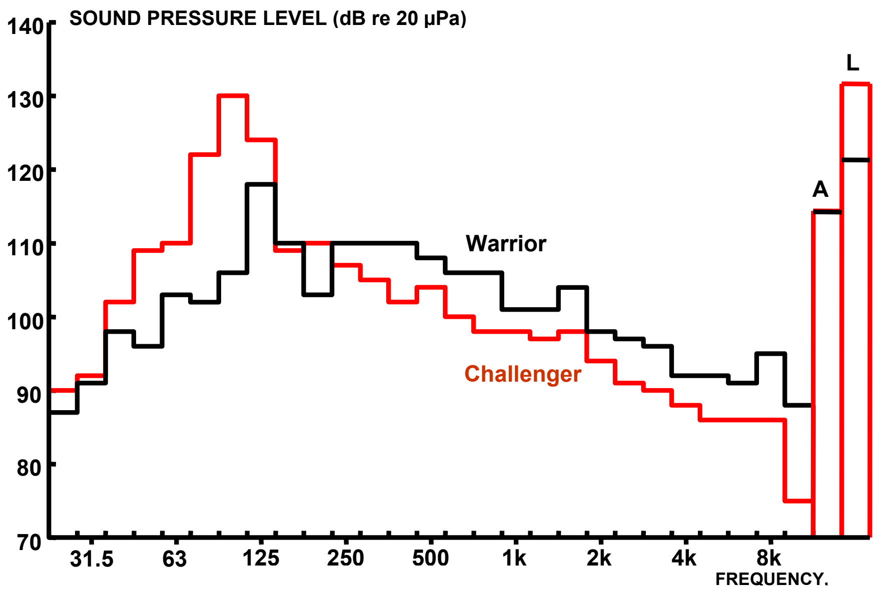

Figure 12: Noise levels inside heavy tanks [5]

3.4 Continuous noise exposure limit

The risk of hearing damage is correlated with the amount of the A-weighted acoustic energy received by the ear (isoenergy principle). An equivalent level of 85 dBA over 8 hours is generally considered as the exposure limit for unprotected ears. For every 3 dB that a LAeq exceeds the limit, the authorized exposure time must be halved: i.e., 4 hours for 88 dB, 2 hours for 91 dB…, 3 seconds for 124 dB! Therefore, in most conditions the exposure of unprotected ears to jet noise, helicopter noise and land-vehicle noise is unpractical and/or prohibited when the regulation is strictly enforced [12,13].

What should be the performance (the Insertion Loss: IL) of the hearing protection to allow a reasonable exposure duration to the noises that have been chosen as examples (§ 3.1, 3.2, 3.3)?

For the jet noise on an aircraft carrier we can estimate that a 10 minutes total exposure to 140-150 dB(A) (corresponding to about 30 launches and recoveries) is an absolute minimum requirement for the deck crew. To comply with the regulation, the hearing protection (HP) must afford an IL of 40-50 dB. No present HP (simple or double) can afford such an IL. If one refuses to break the law and if one does not accept large permanent Noise-Induced Hearing Loss to the personnel, the only solution is to develop new hearing protection devices [4,5].

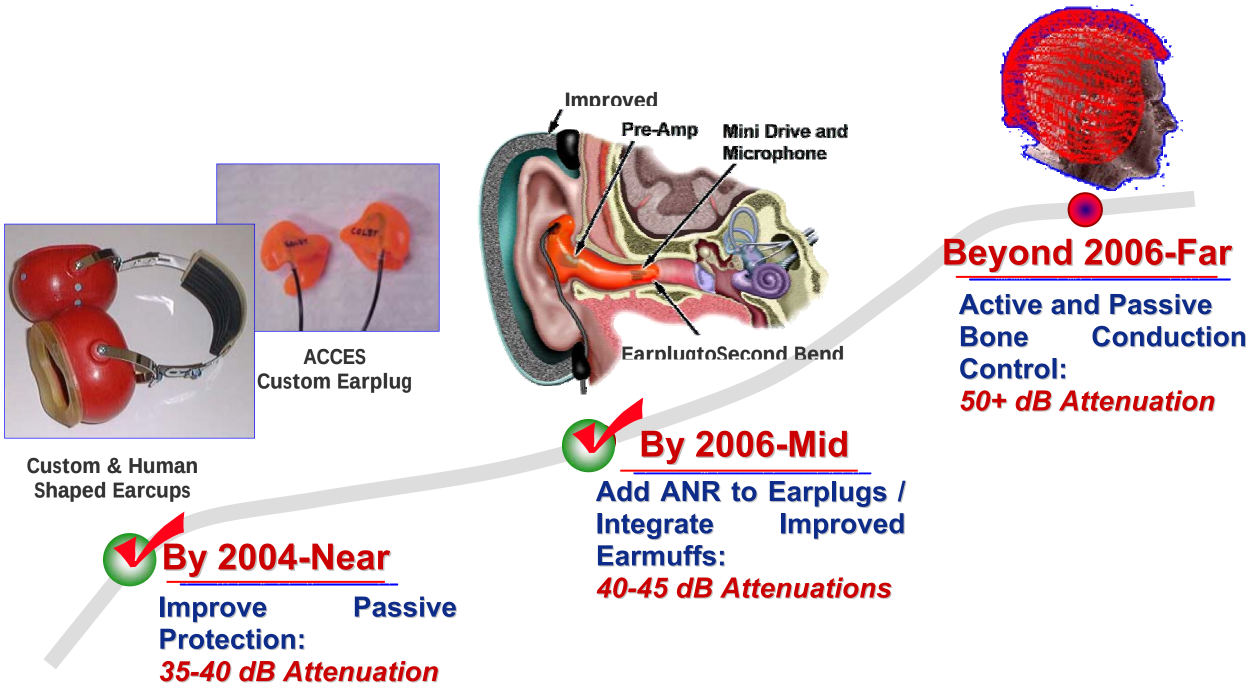

Figure 13: New Hearing Protection Technologies [courtesy: R. McKinley, AFRL/HECB Dayton]

According to [5], present hearing protection available for helicopters must be improved by about 5 dB to stay within legislative criteria. This could be achieved with the help of Active Noise Reduction techniques and/or double hearing protection (earplugs and earmuff).

In the land-vehicles (especially the heavy tanks) the present hearing protectors are generally unable to attenuate sufficiently the high-level noise (about 115 dB(A)) and to allow exposure durations in excess of a few tens of minutes. In these conditions, new (double?) hearing protectors making use of the active noise reduction techniques are necessary.

New hearing protectors will be more expensive and – probably – heavier, more cumbersome and less comfortable (especially if a double hearing protection is used). It will be necessary to ensure that the new hearing protection technologies are affordable, supportable, available and easy to use.

Last but not least, if the occupational noise exposure limit were lowered (i.e., 80 dB(A) instead of 85 dB(A) [13]) and if that new limit were enforced in the army, it is likely that in many situations no practical solution (hearing protection) could be found to comply with a new lower limit.

4.0 IMPULSE NOISE

When a round is fired a large volume of heated gas is released in the surrounding atmosphere. The rapid expansion of the gas initiates a pressure wave that takes the form of a shock wave (figure 14).

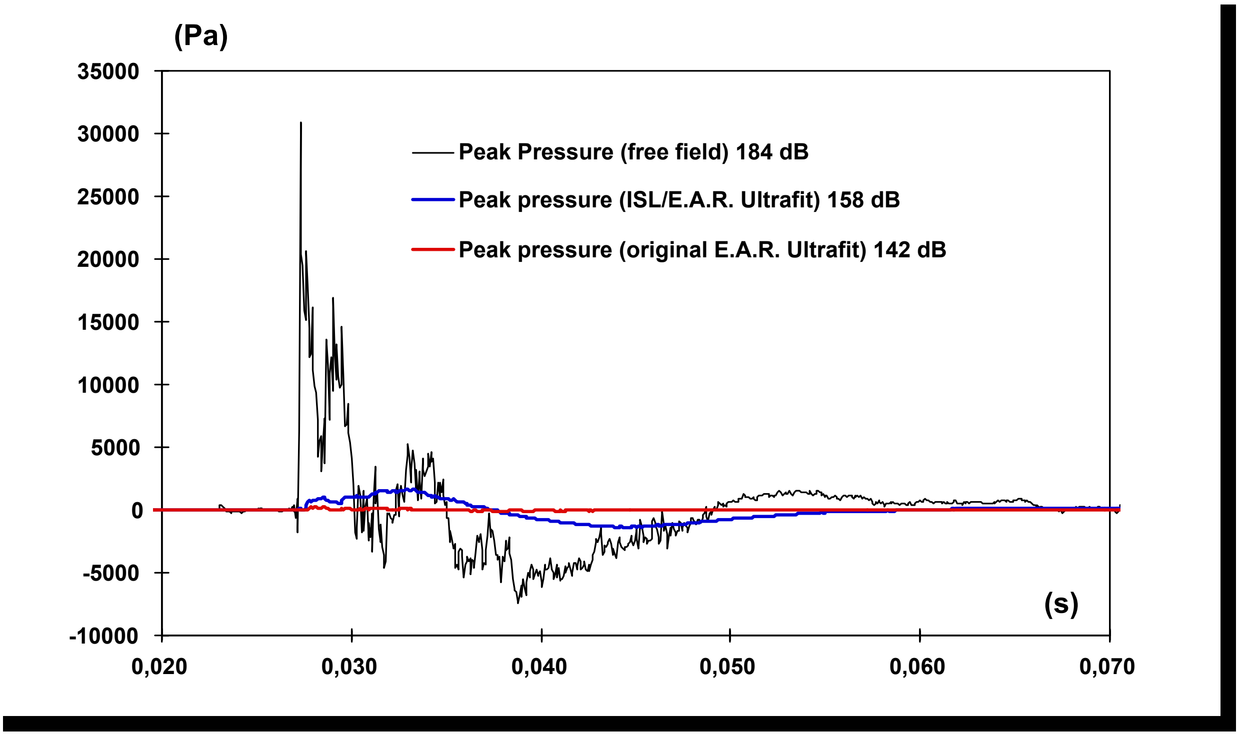

Figure 14: Pressure-time histories (120 mm mortar noise) recorded in free field and at the microphone of the ISL Artificial Test Fixture ear with a nonlinear earplug (ISL/E.A.R. Ultrafit) and a linear earplug (E.A.R. Ultrafit)

For a 120 mm mortar (top charge), the peak pressure at the loader's ear is 185 dB (figures 14 and 15). For a .50 caliber sniper's rifle, the peak pressure at the shooter's ear is 175 dB (figure 15).

4.1 Impulse noise exposure limit

To evaluate the hearing hazard due to weapon noises, a number of criteria have been proposed [14]. These criteria can be divided in three main categories:
- the first one (CHABA, 1968; Pfander criterion, 1980, 1994; MIL STD 1474B (M2), 1984; Smoorenburg criterion, 1982...) uses the peak pressure, the duration(s) (measured in the free field) and the number of the impulses, to evaluate the hazard. Among those, the criteria of Pfander and Smoorenburg (which are characterized by a line with a slope of -3dB/doubling of

either the duration and/or the number of impulses), are roughly in agreement with the iso-energy principle,
- the second one (Atherley and Martin, 1971; Martin, 1976; Dancer, 1982; DTAT, 1983) is based on the (A-weighted) iso-energy principle.
- the third one (Price and Kalb, 1991, 1992) is based on a physico-mathematical model of the auditory periphery. It aims to take into account the actual mechanics of the middle and of the inner ears (including the nonlinearities), up to the highest stimulation levels, and to calculate an index of hazard.

Figure 15: Left: 120 mm mortar, Right: .50 caliber sniper's rifle

These different criteria give different evaluations of the hearing hazard for unprotected ears (this is especially true for the noises of the large weapons). They also disagree on the predicted efficiency of the hearing protectors. No perfect Damage Risk Criterion presently exists (i.e., a DRC able to evaluate accurately the hazard in all exposure conditions: for impulse and continuous noises, for small and large weapons, for free field and reverberant exposures, for protected and unprotected ears...). However, thanks to numerous physical measurements, animal experiments and human observations performed by the members and the experts of the NATO RSG 29 [15] it can be shown that for impulse noises:
- the LAeq8 method with a limit at 85dB allows a limitation of the hearing hazard comparable to that aimed at by the other criteria,
- the LAeq8 method allows the assessment of the hazard for all kinds of weapon noises according to the well-recognized procedure used for occupational exposure (ISO 1999). It can be applied as well to impulses in free field and/or in reverberant conditions (either for small or for large caliber weapons),
- the LAeq8 method does not lead to an excessive overprotection and hence to an unjustified restriction of the use of the weapons as it is the case for most of the other criteria (especially with respect to the large weapon noises),

- the LAeq8 method allows to evaluate the hearing protection afforded by earplugs or earmuffs from classical Insertion-Loss data obtained by Real-Ear-At-Threshold or Acoustical-Test-Fixture methods in a more accurate and less conservative way than most of the other criteria.

This method has been evaluated on soldiers:
- 20 subjects equipped with AEARO foam earplugs are exposed to 20 howitzer (155 mm) rounds (175 dB peak pressure, A-duration: 8 ms, global LAeq8: 109 dB). The Insertion Loss afforded by the plugs is close to 30 dB (in these exposure conditions), therefore the subjects receive a noise dose corresponding to a LAeq8 of 79 dB. No significant TTS is observed.
- 16 subjects equipped with AEARO/ISL nonlinear earplugs are exposed to 7 mortar rounds (185 dB peak pressure, A-duration: 2.5 ms, global LAeq8: 110 dB). The Insertion Loss afforded by the nonlinear plugs is close to 30 dB (in these exposure conditions), therefore the subjects receive a noise dose corresponding to a LAeq8 of 80 dB. No significant TTS is observed (in spite of a peak pressure of 158 dB measured under the plug: figure 14).
- 14 subjects equipped with ISL nonlinear plugs are exposed to 6 shock waves (190 dB peak, A-duration: 1.5 ms, global LAeq8: 114 dB) (Albuquerque study). The Insertion Loss afforded by the nonlinear plugs is close to 30 dB (in these exposure conditions), therefore the subjects receive a noise dose corresponding to a LAeq8 of 84 dB. No significant TTS is observed in all but one subject.
- groups of 10 subjects equipped with an earmuff are exposed to 100 shock waves (187 dB peak pressure, A-duration 3 ms, 1 minute interval) (Albuquerque study). No significant TTS is observed (in spite of a peak pressure of 173 dB measured under the earmuff).

Then, we can conclude that the criterion based on the measurement of the A-weighted energy with a limit at 85 dB LAeq8 allows to assess satisfactorily the hazard corresponding to impulse noise *and* the actual efficiency of the hearing protectors. Consequently, at first sight impulse noise is not a limiting factor for the use of modern weapons.

However, the new European directive that will be enforced on February 2006 [13] prohibits the exposure to *a residual peak pressure higher than 137 dB(C) under the hearing protection*. This demand is scientifically and experimentally unfounded (see above) and originates (i) from a misreading of the actual acoustical, biomechanical and physiological phenomena related to hearing protection *versus* impulse/weapon noise and (ii) from an insufficient exchange of data between the military experts and the occupational law makers. If this new regulation were to be applied to the weapon noises, only light weapons could still be used *with a double hearing protection* (earplugs and earmuff). In all other cases (medium and heavy weapons), the residual peak pressure under the hearing protection will exceed 137 dB(C) whatever hearing protection is in use.

5.0 CONCLUSION

The noise of the modern weapon systems is a limiting factor for their use either because no present hearing protection is able to protect the ear and to avoid a large deterioration of the voice communication (continuous noise), or because unsuited regulation will make their use impossible (impulse noise).

REFERENCES

[1] Dancer, A., “Hearing and Hearing Protection”, NATO Lecture Series 244/HFM-111, 2004
[2] Peters, L., Garinther, G., "The effects of speech intelligibility on crew performance in an M1A1 tank simulator", US Army Human Eng. Lab,Techn. Memorandum, 1990, 11
[3] Ohlin, D., “Cost effectiveness of hearing conservation programs”, NATO Lecture Series 219, RTO-EN-11, AC/323(HFM)TP/31, 2000
[4] McKinley, R., “Passive hearing protection systems and their performance”, NATO Lecture Series 244/HFM-111, 2004
[5] James., S. and McKinley, R., “Applications overview of military noises, insertion loss, prediction of performance”, NATO Lecture Series 244/HFM-111, 2004
[6] Dancer, A., “Individual susceptibility to NIHL and new perspective in treatment of acute noise”, NATO Lecture Series 219, RTO-EN-11, AC/323(HFM)TP/31, 2000
[7] Buck, K., Wessling, T. and Dancer, A., “Adapting the STI for the use in very noisy environments”, 7th Intl. Congress on Noise as a Public Health Problem, Sydney, 1998, 163
[8] Buck, K., “Active hearing protection systems and their performance”, NATO Lecture Series 244/HFM-111, 2004
[9] Steeneken, H., “Assessment and standardization”, NATO Lecture Series 244/HFM-111, 2004
[10] van Wijngaarden, S. and James, S., “Protecting crew members against military vehicle noise”, NATO Symposium, AVT-110, Prague, 4-8 October, 2004
[11] Dancer, A., “Noise in the French Army Land Vehicles: consequences on Hearing Protection and Communication”, NATO Symposium, AVT-110, Prague, 4-8 October, 2004
[12] ISO 1999 2nd Edition (1990) “Acoustics: Determination of occupational noise exposure and estimation of noise-induced hearing impairment”, Geneva, International Standards Organization
[13] Physical Agents Directive 2003/10/EC, Official Journal of the European Communities, February 15, 2003
[14] Dancer, A. and Franke R., "Hearing Hazard from Impulse Noise: a Comparative Study of Two Classical Criteria for Weapon Noises (Pfander Criterion and Smoorenburg Criterion) and the LAeq8 Method", Acta Acustica, 3, 539-547, 1995
[15] NATO Research Study Group on the Effects of Impulse Noise, AC/243 (Panel 8/RSG 6) D/9, February 1987